

Estimation of Averages of Radiation and Illumination1. Data

Records of daily values of radiation and illumination on a horizontal surface have been taken at Kew since 1947 in units of gram-Calories per sq-cm. (R) and Kilolux (I). Although they are not all of an equal standard of accuracy, 12 years of data are now available.

2. Initial Analysis

The data were divided into 3 10-day periods per month. A simple regression against sunshine hours was computed for each of these 36 periods, i.e. Jan. 1-10, Jan. 11-20, Jan. 21-31 and so on. Considering the possibility of unknown errors in the data and the other unconsidered meteorological factors involved the results were reasonably consistent, but slight irregularities in the terms were apparent. To obviate these, the coefficients were plotted on a time scale a smooth curve was drawn and the monthly values read off at the appropriate points with the following results.

Table I

<u>Month</u>	<u>Radiation</u>	<u>Illumination</u>
January	10.0 S + 37	11.6 S + 48
February	15.6 S + 61	18.4 S + 77
March	23.0 S + 101	25.6 S + 128
April	28.0 S + 140	34 24.0 S + 185
May	31.2 S + 178	39 30.2 S + 240
June	32.0 S + 212	40.8 S + 300
July	30.6 S + 200	40.2 S + 288
August	28.0 S + 164	37.2 S + 236
September	22.8 S + 126	30.4 S + 180
October	16.6 S + 83	20.0 S + 113
November	11.8 S + 46	13.2 S + 62
December	9.2 S + 30	9.6 S + 40

S = mean sun hours

3. The effect of haze

It is reasonable to assume that a considerable factor is the presence or absence of haze. Figures are available, from an earlier investigation, of the average number of days per month at about 60 stations, when the afternoon visibility was (a) below 4,400 yards and (b) below $6\frac{1}{4}$ miles. It is tempting to use the sum of these two parameters as a "visibility factor" (V).

If S is eliminated between the two sets of expressions in Table I, we obtain for Kew:-

Table II

<u>Month</u>	<u>Value of R in terms of I</u>	<u>Mean Visibility Factor (V)</u>
January	0.86 I - 0.4	43
February	0.85 I - 0.3	33
March	0.90 I - 0.6	30
April	0.82 I - 0.4	15
May	0.80 I - 0.4	11
June	0.78 I - 0.7	7
July	0.76 I - 0.6	6
August	0.75 I - 0.4	6
September	0.75 I - 0.4	9
October	0.83 I - 0.6	24
November	0.90 I - 0.8	39
December	0.96 I - 0.9	44

Multiply
Constants
by 10

The correlation between the coefficient of I and the visibility factor is 0.9, which suggests that although the relationship between R and I is approximately constant, it does vary closely with the visibility in the afternoons. The mean value of the relationship is

$$R = 0.83 I - 0.5$$

when R and I are in the units previously mentioned.

4. Further Analysis

The availability of the computer to perform multiple regression analysis enabled further analysis to be made to try to establish a relationship between R (and I) and sunshine, temperature, rainfall and visibility (V). Some close relationships were found but they were not consistent in form from month to month. In other words, the computer found a nearest straight line but it did not find the nearest sensible straight line. For example, there were occasions when the coefficient of V was positive, implying that in a completely foggy month, illumination would be at a maximum. However closely such equations fitted the Kew data, they were manifestly useless for extrapolation elsewhere.

5. Final Analysis

Some subterfuge was inevitable. It was therefore decided to apply the expressions of Table I to each monthly mean and to find a relationship between the errors so obtained and the visibility factor (V). During some summer months when V was small, no improvement in fit was possible. To attempt to eliminate possible errors in R and V, the two years with the worst fit were discarded. In most cases these were the 1947 or 1948 readings. The results so obtained were:-

Table III

<u>Month</u>	<u>Radiation</u>	<u>Mean percentage error in 10 "best" years</u>
January	10.0 S - 0.3 V + 50	5.6
February	15.6 S - 0.9 V + 92	6.0
March	23.0 S - 1.25 V + 136	5.1
April	28.0 S - 3.0 V + 196	6.3
May	31.2 S - 5.0 V + 240	4.9
June	32.0 S - 3.7 V + 234	6.9
July	30.6 S + 200	5.1
August	28.0 S + 164	5.9
September	22.8 S - 0.6 V + 136	5.0
October	16.6 S - 0.35 V + 92	7.2
November	11.8 S - 0.25 V + 55	4.6
December	9.2 S - 0.35 V + 45	5.7 <u>Mean 5.7%</u>

Table IV

<u>Month</u>	<u>Illumination</u>	<u>Mean Percentage error in 10 "best" years</u>
January	11.6 S - 0.75 V + 75	6.5
February	18.4 S - 0.45 V + 86	6.3
March	25.6 S - 1.2 V + 152	3.6
April	34.0 S - 4.3 V + 258	5.8
May	39.2 S + 240	4.6
June	40.8 S - 5.0 V + 320	6.4
July	40.2 S - 2.35 V + 270	4.1
August	37.2 S - 3.15 V + 257	6.4
September	30.4 S - 0.3 V + 183	5.7
October	20.0 S - 0.2 V + 110	5.0
November	13.2 S - 0.8 V + 93	5.4
December	9.6 S - 0.35 V + 54	2.8 <u>Mean 5.2%</u>

6. Extrapolation

The expressions in Table III and IV can be used to estimate average values of radiation and illumination using standard normal data and the visibility data mentioned in para. 3, provided that the figures so obtained were corrected by a factor depending on the strength of the sun at various latitudes. The results are given in Tables V and VI (nearest 5 units).

For areas other than in England and Wales, no visibility data were available, so for Scotland, Northern Ireland and the Channel Isles, the expressions of Table I were used in the same way. The results are given in Tables VII and VIII (nearest 5 units).

7. Degree of Inaccuracy

As the expressions of Table I were established for a hazy area, the estimates in Tables VII and VIII are probably too low, but if maps are plotted using data obtained by both types of formula, there is no very obvious discontinuity at the Scottish border, so that such inaccuracy may be small especially in summer.

For year-to-year values these expressions can lead to errors at Kew up to 10 per cent, and on extrapolation this error must increase. For average values, the position is eased, owing to cancellation of yearly errors, and it is suggested that the absolute errors at any one station should be within the 10 per cent range. The relative errors are probably much less, and it is for this reason that these figures are now made available as they may be found to be useful in problems such as horticulture planning, siting of glasshouses etc. They should only be regarded as an interim guide until better information becomes available, in other words, as a first approximation.

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Estimated Average Daily Radiation

in gram-Calories per square-cm.

<u>ENGLAND & WALES</u>	<u>Jan.</u>	<u>Feb.</u>	<u>Mar.</u>	<u>Apr.</u>	<u>May</u>	<u>June</u>	<u>July</u>	<u>Aug.</u>	<u>Sept.</u>	<u>Oct.</u>	<u>Nov.</u>	<u>Dec.</u>
Acklington	45	100	185	295	370	405	360	295	220	125	60	35
Tynemouth	40	90	175	285	340	390	365	295	220	120	60	30
Catterick	45	95	170	280	330	385	365	290	220	120	60	35
Leeming	45	100	175	280	340	390	365	295	210	120	60	35
Harrogate	45	95	175	280	335	395	365	300	210	125	60	35
Driffield	45	95	180	290	365	385	365	305	225	130	60	35
Squires Gate	45	95	180	315	410	430	380	315	225	125	60	35
Southport	45	95	175	295	365	425	380	315	220	125	60	35
Liverpool (Speke)	50	95	180	295	355	410	390	310	215	125	60	40
Manchester	40	80	155	245	325	365	335	285	195	110	50	30
Church Fenton	45	90	160	255	345	370	365	300	215	120	60	35
Finningley	45	95	175	280	370	380	370	310	220	125	60	35
Spurn Head	50	100	185	290	355	400	390	315	210	130	65	40
Holyhead	55	115	200	325	410	440	380	320	230	135	70	45
Hawarden	50	100	180	290	350	415	370	305	220	125	60	40
Shawbury	55	105	185	300	370	420	370	305	225	130	65	45
Watnall	45	90	175	280	350	380	365	310	220	125	60	35
Cranwell	50	100	185	300	385	420	390	325	230	135	65	40
Wittering	55	100	190	305	380	405	380	320	235	140	70	40
Mildenhall	55	110	200	315	425	440	405	335	245	140	75	45
West Raynham	55	110	195	315	415	430	395	335	245	140	70	45
Yarmouth	50	105	195	285	350	410	405	335	240	140	70	45
Aberporth	60	120	205	335	415	430	385	310	235	140	75	55
St. Ann's Head	60	120	210	320	390	430	385	320	235	140	75	55
St. Athan	60	120	195	310	395	435	400	320	235	140	75	50
Ross-on-Wye	60	115	205	315	385	430	375	315	230	135	70	50
Defford	55	110	195	310	370	420	385	315	235	135	75	50
Birmingham	45	90	165	255	310	395	365	305	215	125	60	40
Henley	50	100	175	295	355	405	375	310	225	135	65	40
Little Rissington	55	110	190	315	405	425	380	315	240	135	70	50
Cranfield	55	110	195	300	415	430	380	320	230	140	70	45
Dunstable	55	105	195	295	380	410	380	325	245	140	70	45
Felixstowe	60	115	210	320	415	455	415	345	250	145	75	50
Bristol	60	115	205	330	400	445	400	320	245	140	75	50
Lyneham	60	115	200	325	400	430	390	320	245	135	75	50
Larkhill	65	120	210	340	415	445	395	335	250	145	80	50
Boscombe Down	60	115	200	325	400	440	395	330	245	140	75	50
Worthy Down	60	120	210	345	425	445	400	335	250	145	80	50
Abingdon	60	115	200	315	410	430	385	320	240	140	75	50
South Farnborough	60	115	205	315	395	450	405	340	245	145	75	50
Kew	50	95	180	280	375	435	395	330	235	135	65	40
Croydon	50	95	185	280	370	440	405	335	240	140	65	40
Greenwich	45	80	160	230	340	415	390	325	230	130	60	35
Biggin Hill	60	105	195	300	390	430	400	335	245	145	70	45
West Malling	60	110	200	310	410	445	410	340	255	150	75	45
Shoeburyness	60	115	210	315	415	455	415	345	250	145	75	50
Scillies	70	135	230	360	415	445	400	350	255	160	90	65
St. Eval	65	130	225	355	410	450	400	340	250	155	85	60
Lizard	75	130	230	350	410	445	420	345	255	160	90	65
Falmouth	75	130	225	345	415	465	400	345	255	155	95	65
Hartland Point	65	130	225	345	420	455	400	330	245	150	85	60
Plymouth	70	125	225	340	415	450	395	355	255	155	85	60
Exeter	70	130	220	355	430	470	410	340	255	150	85	60
Portland Bill	70	130	220	335	420	455	425	355	260	155	90	60
Holton Heath	65	125	215	330	410	450	415	345	255	145	90	55
Calshot	65	125	220	335	415	460	420	355	255	155	90	55
Thorney Island	65	120	220	340	425	460	420	350	260	155	85	55
Tangmere	65	125	220	325	420	450	420	350	260	155	85	55
Dungeness	65	125	210	325	410	435	430	360	260	155	85	55
Lympe	60	120	220	325	420	460	425	355	255	150	80	55
Manston	60	115	210	330	420	435	425	365	255	150	80	50

Estimated Average Daily Radiation
in gram-Calories per square-cm.

<u>SCOTLAND</u>	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
Stornoway	25	65	150	255	360	385	325	265	180	95	35	15
Portrose	30	75	155	250	340	395	335	275	185	105	40	20
Inverness	30	75	155	245	335	390	330	275	185	100	40	20
Gordon Castle	30	75	155	245	345	390	335	280	190	105	40	20
Banff	30	75	155	250	345	395	340	280	190	105	40	20
Aberdeen	30	75	155	250	345	405	340	280	195	105	34	20
Arbroath	35	85	165	270	365	430	365	295	210	115	50	25
Oban	30	70	155	255	360	395	330	270	185	100	45	25
Perth	35	80	155	260	345	415	355	280	200	110	45	25
Dundee	35	80	160	255	340	405	345	280	200	110	50	25
Leuchars	35	85	165	270	360	425	360	290	210	115	50	25
Rothsay	35	75	155	260	360	410	345	280	195	105	50	25
Helensborough	35	75	155	250	350	400	335	270	190	105	45	25
Renfrew	35	75	155	255	345	400	345	275	195	105	45	25
Stirling	35	75	155	250	330	395	330	270	195	105	45	25
Boghall	35	80	160	250	335	405	345	275	200	110	50	25
North Berwick	35	80	160	260	350	420	360	285	200	110	45	25
Kilmarnock	35	80	160	260	365	405	340	280	200	110	50	25
Turnberry	35	85	165	270	380	415	350	290	200	110	50	30
Dumfries	40	80	165	255	360	415	345	285	195	115	55	30
Eskdalemuir	35	80	155	245	340	390	335	270	190	110	50	30
Marchmont	35	75	160	250	345	405	345	280	195	105	50	25
Aldergrove	40	85	165	265	375	400	330	280	200	115	55	30
Douglas I. o. M.	45	90	180	290	395	440	375	315	220	125	60	35
Guernsey	65	115	220	330	415	490	445	380	270	155	80	50

Estimated Average Daily Illumination

in Kilolux

ENGLAND & WALES	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
Acklington	50	105	205	375	455	535	460	405	295	150	85	45
Tynemouth	50	100	200	355	455	510	460	390	295	150	80	40
Catterick	55	105	195	355	445	510	465	395	280	145	85	40
Leeming	60	105	200	355	450	515	470	400	285	145	85	45
Harrogate	55	105	200	350	455	520	460	395	280	150	80	45
Driffield	60	105	200	365	460	505	470	415	300	160	85	45
Squires Gate	55	105	205	395	495	565	500	425	300	155	80	40
Southport	55	105	200	365	500	570	485	420	295	155	75	40
Liverpool (Speke)	65	110	200	370	475	545	475	415	290	155	85	50
Manchester	50	90	175	305	440	485	425	380	265	135	65	35
Church Fenton	55	100	185	315	450	490	450	400	290	150	80	40
Finningley	55	105	200	350	460	505	470	410	295	155	80	45
Spurn Head	60	110	210	360	475	530	485	410	285	160	90	50
Holyhead	75	120	225	410	515	575	490	435	310	165	105	55
Hawarden	65	110	205	360	475	545	475	415	290	155	85	50
Shawbury	70	110	215	375	475	555	480	415	300	155	95	50
Watnall	55	105	200	350	460	505	470	425	295	155	80	40
Cranwell	60	110	215	375	485	560	500	440	305	165	85	50
Wittering	65	110	215	385	490	535	490	440	315	170	90	50
Mildenhall	70	120	225	400	500	580	530	475	325	175	100	50
West Raynham	65	120	225	400	505	570	515	465	325	175	95	50
Yarmouth	65	115	220	350	500	555	510	435	320	170	90	55
Aberporth	85	125	230	425	480	565	505	435	315	170	110	60
St. Ann's Head	80	130	240	400	500	570	490	435	310	170	110	60
St. Athan	75	130	225	385	495	570	515	440	320	170	105	60
Ross-on-Wye	80	125	225	400	470	570	490	445	310	165	100	60
Defford	75	120	220	395	480	555	500	440	315	165	105	55
Birmingham	55	105	190	315	450	520	465	425	290	155	80	45
Honiley	65	110	200	370	475	535	480	425	300	165	90	50
Little Rissington	70	120	215	395	485	565	500	445	320	165	100	55
Cranfield	75	120	220	375	490	565	490	450	320	175	100	55
Dunstable	70	115	220	370	490	540	490	450	325	170	95	55
Felixstowe	75	125	240	405	520	600	540	480	335	180	100	60
Bristol	75	125	230	415	490	585	520	450	325	170	100	60
Lyneham	80	125	225	415	485	570	510	450	330	165	105	60
Larkhill	80	130	235	420	490	590	515	470	335	175	110	60
Boscombe Down	80	125	225	410	490	580	515	465	330	170	105	60
Worthy Down	80	130	240	430	500	590	535	470	335	180	100	60
Abingdon	80	120	225	400	485	565	505	450	320	170	105	60
South Farnborough	75	125	235	400	495	590	525	470	330	180	105	60
Kew	60	110	205	350	485	575	510	460	315	165	85	50
Croydon	60	110	210	350	490	580	515	465	320	170	85	50
Greenwich	45	100	190	280	470	545	500	450	305	165	70	45
Biggin Hill	70	120	220	375	505	565	515	455	330	175	95	55
West Malling	75	125	225	390	510	585	530	465	340	180	100	55
Shoeburyness	75	125	240	400	515	600	540	480	335	180	100	60
Scillies	100	140	255	435	525	585	515	480	340	195	130	75
St. Eval	90	135	255	430	505	595	520	465	340	185	125	70
Lizard	100	140	255	440	510	585	540	465	345	190	135	75
Falmouth	100	140	255	435	510	610	515	480	340	190	130	75
Hartland Point	90	135	250	435	500	600	520	460	335	180	125	70
Plymouth	90	135	255	430	505	595	510	490	340	190	120	70
Exeter	95	135	250	445	510	615	540	480	340	185	125	70
Portland Bill	95	135	250	425	520	600	550	495	350	190	130	70
Holton Heath	85	135	240	415	515	595	535	470	345	175	115	65
Calshot	85	135	250	420	525	605	545	490	340	190	115	65
Thorney Island	85	135	245	425	535	605	545	480	350	185	115	65
Tangmere	80	135	245	405	535	595	540	480	350	190	115	65
Dungeness	85	135	240	405	540	575	545	475	345	190	120	65
Lyapne	75	130	250	410	525	620	550	490	340	185	105	60
Manston	75	130	240	415	540	590	550	500	345	185	110	60

Estimated Average Daily Illumination
in Kilolux

<u>SCOTLAND</u>	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
Stornoway	30	80	180	325	470	520	455	370	250	125	50	20
Fortrose	40	90	185	320	445	535	465	380	260	135	55	25
Inverness	40	90	185	310	435	525	460	380	260	135	55	25
Gordon Castle	40	90	185	315	445	530	465	385	260	135	55	25
Banff	40	90	185	320	450	535	470	390	265	135	50	25
Aberdeen	40	90	185	315	445	545	475	390	275	140	55	30
Arbroath	45	100	200	345	475	585	505	405	290	150	65	30
Oban	40	90	185	325	470	535	460	375	255	130	55	30
Perth	40	95	190	330	450	560	490	390	275	140	60	30
Dundee	45	100	190	325	440	545	480	390	275	145	60	30
Leuchars	45	100	200	340	465	575	500	400	290	150	65	30
Rothsay	45	95	190	330	470	550	475	390	275	135	60	30
Helensborough	40	90	185	320	455	540	465	380	260	135	60	30
Renfrew	40	90	185	320	450	545	475	380	270	135	60	30
Stirling	40	95	190	320	430	535	460	375	270	140	60	30
Boghall	45	100	190	320	435	550	475	385	275	145	65	35
North Berwick	45	100	195	330	455	565	500	395	280	140	60	30
Kilmarnock	45	95	190	330	475	550	470	390	275	140	60	35
Turnberry	45	100	200	345	490	560	485	405	280	145	65	35
Dunfries	50	100	195	325	465	555	480	395	275	150	65	35
Eskdalemuir	45	100	190	315	445	530	460	375	260	145	65	35
Marchmont	45	95	190	320	445	550	480	390	275	140	60	35
Aldergrove	50	100	200	335	490	540	460	390	275	150	70	40
Douglas I. o. M.	55	105	215	370	510	595	520	435	305	165	75	45
Guernsey	80	140	265	415	535	655	615	520	370	200	100	65